13th International Workshop on Plasma Edge Theory in Fusion Devices 19-21 September, 2011 Embassy Suites Hotel South Lake Tahoe, California USA

Simulation study of L/H transition with self-consistent integrated modelling of core and SOL/Divertor transport

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Contents of My Talk

■**Activity of Integrated Transport Modelling in Japan**

BPSI, (BA IFERC/CSC)

■**Core-Edge Coupling Model: TASK/TOPICS + SONIC**

■**Application of TOPICS+SONIC to L/H Transition Dynamics**

- **Empirical Transport Model**
  K. Shimizu et al., 23th FEC, Daejon, 2010, THD/5-2Ra

- **Tuned Current Diffusive Ballooning Model (CDBM) Transport Model**

First Topic

✓**Activity of Integrated Transport Modelling in Japan**

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■**Core-Edge Coupling Model: TASK/TOPICS + SONIC**

■**Application of TOPICS+SONIC to L/H Transition Dynamics**

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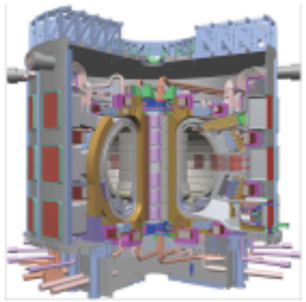
GENERAL OUTLINE

Establishment of quantitative description of burning plasmas in ITER

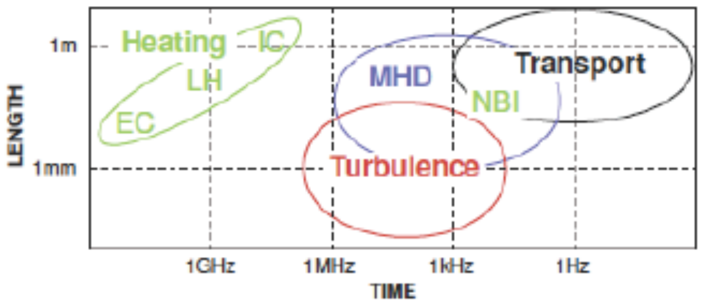
Development of integrated transport simulation with various modules

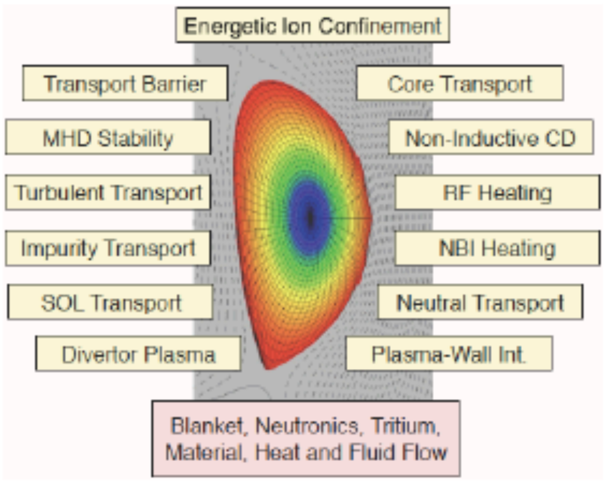
ITER



A. Fukuyama and M. Yagi, 'Burning Plasma Simulation Initiative and Its Recent Progress', J. Plasma Fusion Res. Vol.81, No.10 (2005) 747-754.

Reliable prediction and control



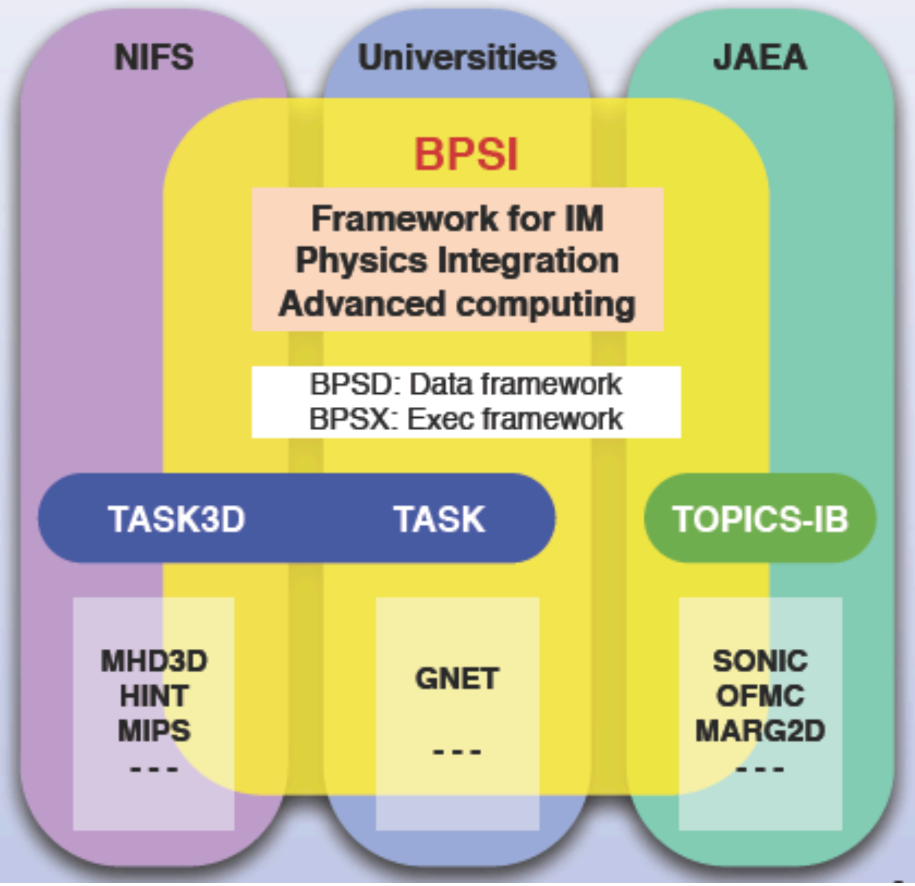


Time scale 10ps (100GHz) ~ 1000s, spatial scale 10μm ~ 10m

Burning plasma includes multi-scale, multi-physics phenomena

Integrated Modeling Activity in Japan

Burning Plasma Simulation Initiative (BPSI)
Research collaboration of universities, NIFS and JAEA

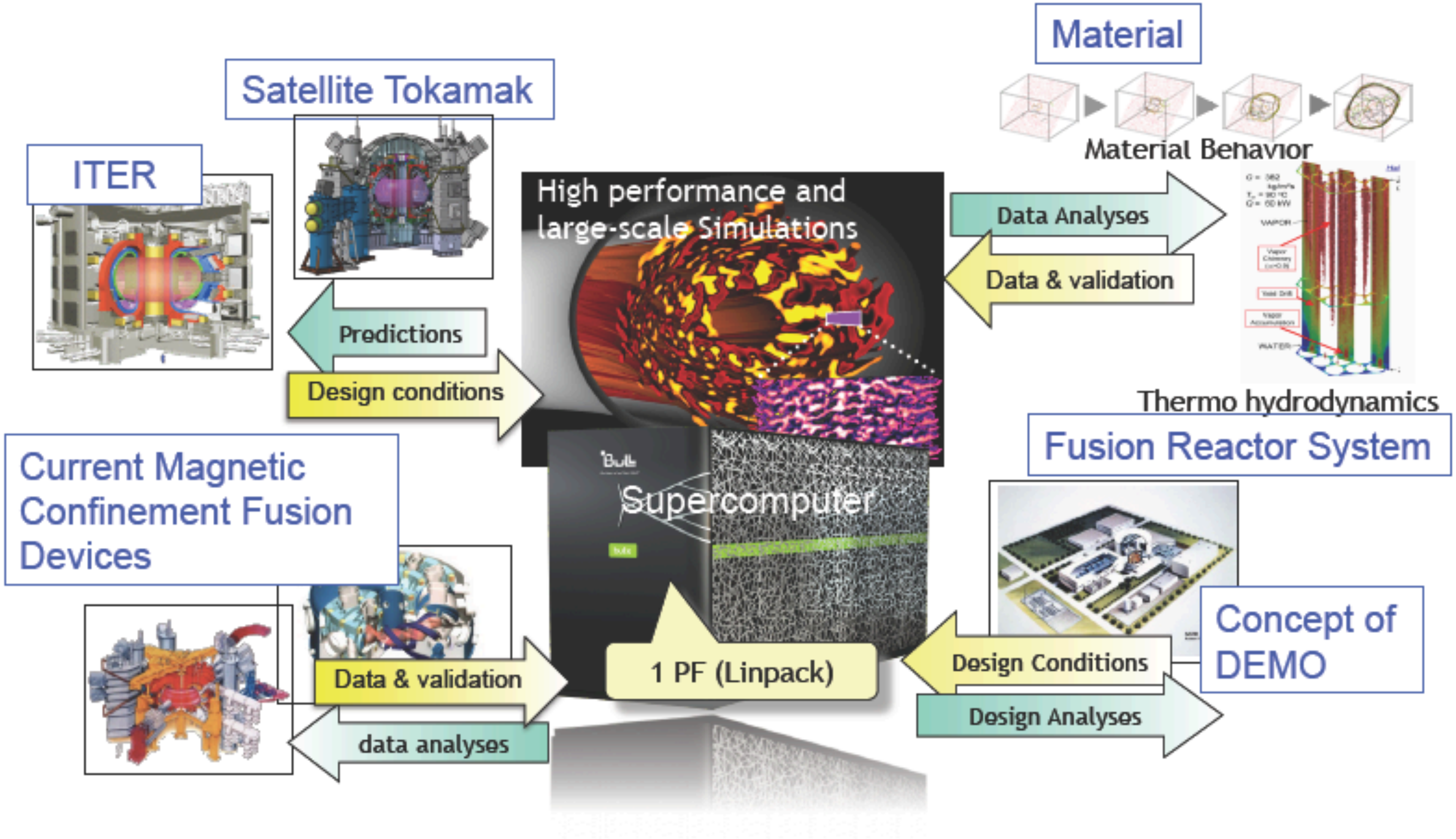


BA Site in Rokkasho

- In March, 2010 main buildings in BA site are completed.

Research Fields for IFERC CSC High Performance Computing System

- Plasma Physics for the Magnetic Confinement Fusion
- Research for Fusion Development (ITER & BA)
- Research for DEMO Design and R&D
- Research for Material for Fusion Reactor



Second Topic

■ **Activity of Integrated Transport Modelling in Japan**

BPSI, (BA IFERC/CSC)

✓ **Core-Edge Coupling Model: TASK/TOPICS + SONIC**

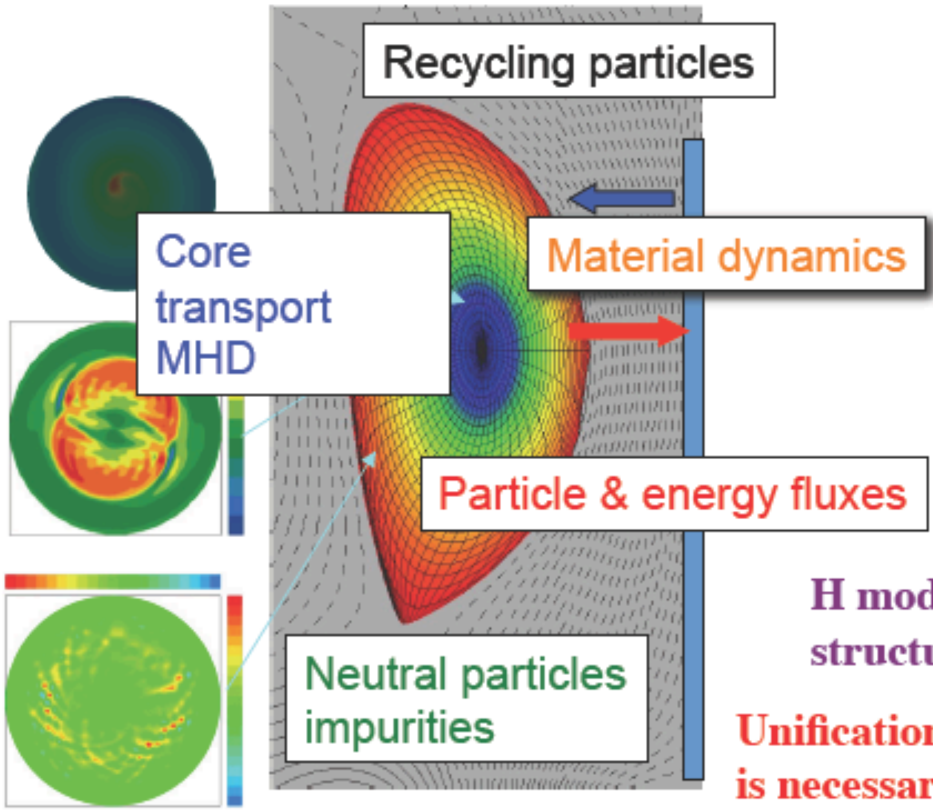
■ **Application of TOPICS+SONIC to L/H Transition Dynamics**

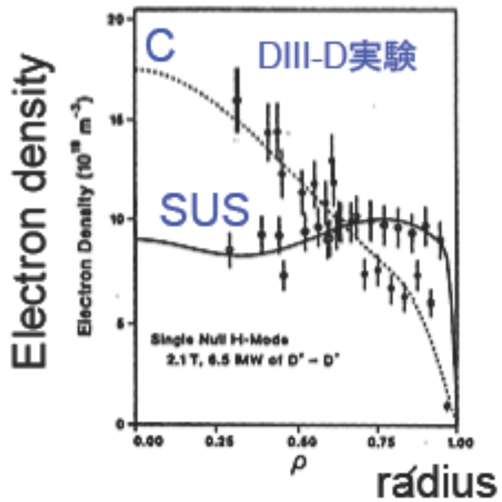
- **Empirical Transport Model**
  K. Shimizu et al., 23th FEC, Daejon, 2010, THD/5-2Ra

- **Tuned Current Diffusive Ballooning Model (CDBM) Transport Model**

Integrated Transport Code

Inclusion of plasma, atomic/molecule and material dynamics
Handle with multi-scale, multi-physics, complex phenomena



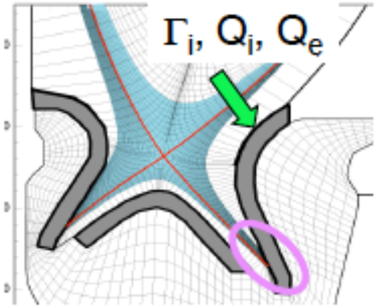


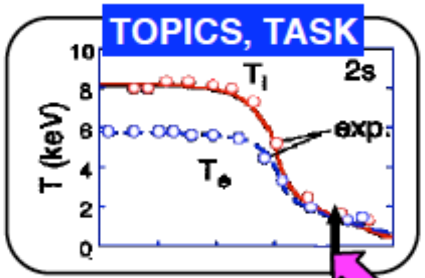
H mode characteristics depends on structural material

Unification of plasma science and material science is necessary for the success of ITER

M. Yagi et al., 11th PET, Takayama 2009

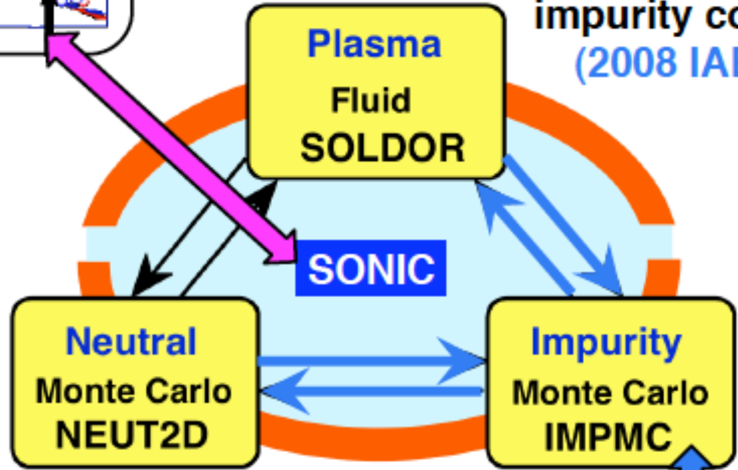
Integrated Divertor Code “SONIC”





The divertor code is indispensable in divertor design work.

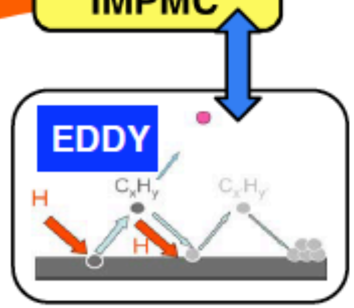
coupling of an MC impurity code (2008 IAEA)



•Interaction with core edge (2010 IAEA)

core transport $\xrightarrow{F_i, Q_i, Q_e}$ SOL/divertor

core transport $\xleftarrow{S_n, P_{cx}, P_{rad}}$ SOL/divertor



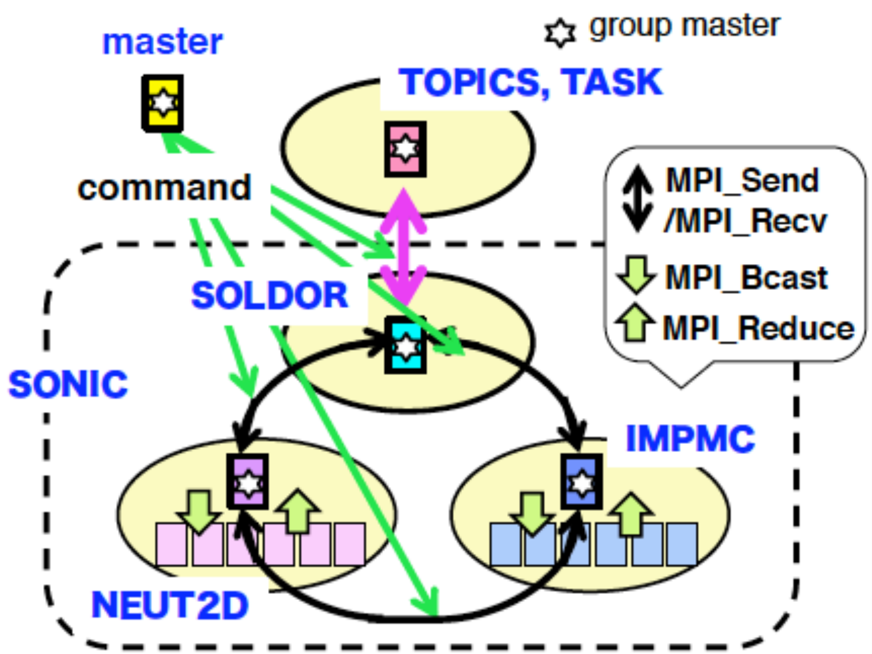
SONIC has been consistently coupled to a 1.5 D tokamak transport code (TOPICS-IB and TASK).

similar integrated codes : JINTRAC (EU) and FACETS (US)

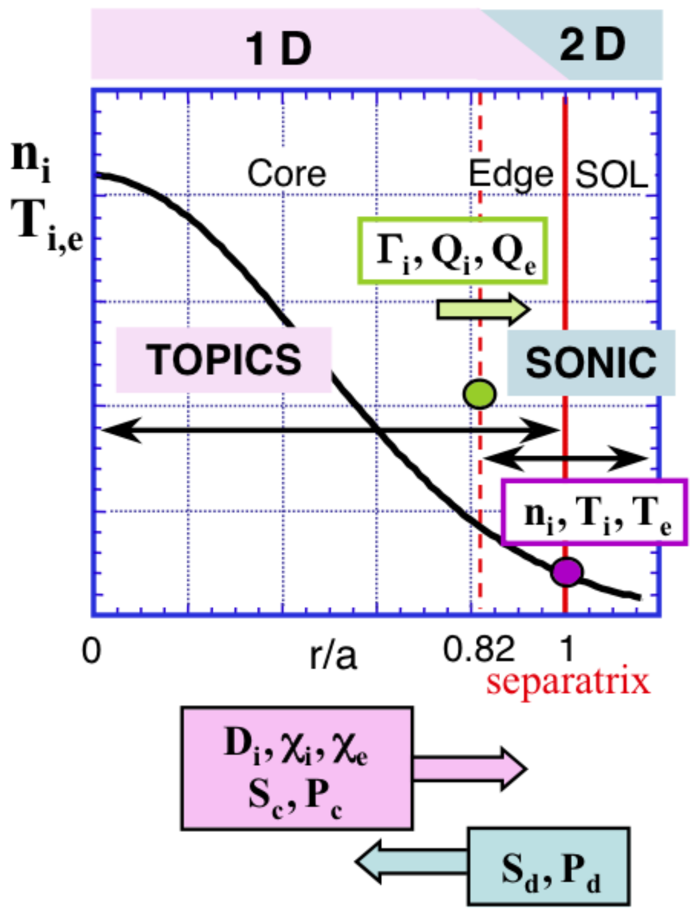
Coupling to the Core Transport Code

New MPMD parallel computing System

enables unification of independently established code suite efficiently.



Relation between TOPICS and SONIC



Data exchange in every 200 μs

Third Topic

■ **Activity of Integrated Transport Modelling in Japan**

BPSI, (BA IFERC/CSC)

■ **Core-Edge Coupling Model: TASK/TOPICS + SONIC**

✓ **Application of TOPICS+SONIC to L/H Transition Dynamics**

- **Empirical Transport Model**
  K. Shimizu et al., 23th FEC, Daejon, 2010, THD/5-2Ra

- **Tuned Current Diffusive Ballooning Model (CDBM) Transport Model**

Transport Modelling

High current operation of JT-60SA (Ip = 5.5 MA, BT=2.25 T)

Diffusion coef. in the main plasma

(simple empirical model : Hayashi N. et al. 2009 Nucl. Fusion **49** 095015)

$$\chi_i(\rho) = \chi_e(\rho) = 2 \times D_i(\rho)$$
$$= 0.3 \cdot (1 + 2\rho^2) \times \sqrt{1 + P_{NB} / P_{OH}}\ \mathrm{m^2/s}$$

H-mode phase

$$0.9 < r/a < 1.0$$

$$D_i = 0.1\ \mathrm{m^2/s},\ \chi_i = \chi_e = 0.2\ \mathrm{m^2/s}$$

Diffusion enhanced by ELM crash

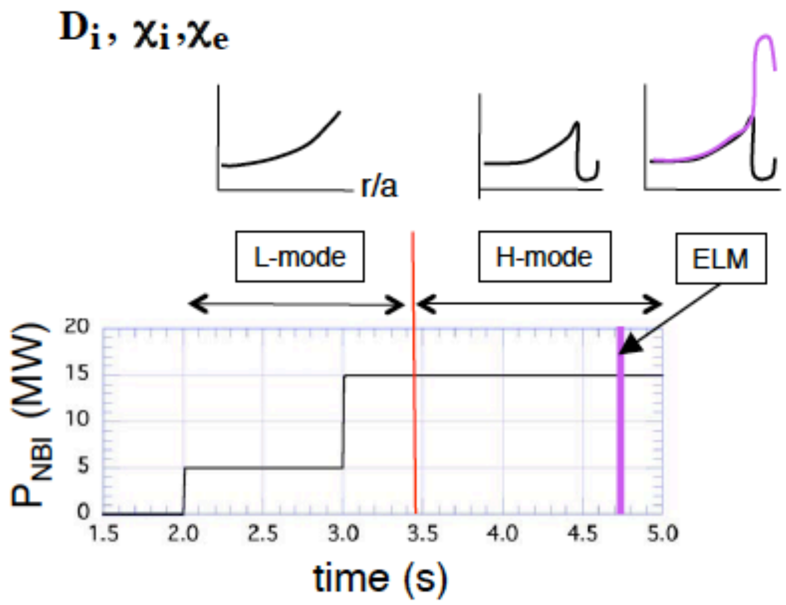
$$D_i = 50\ \mathrm{m^2/s},\ \chi_i = \chi_e = 50\ \mathrm{m^2/s}$$

during 200 μs

Diffusion coef. in SOL/Divertor region

are fixed throughout the simulation;

$$D_i = 0.3\ \mathrm{m^2/s},\ \chi_i = \chi_e = 1\ \mathrm{m^2/s}$$



For simplicity (mainly to reduce cpu time), simple radiation model (Non coronal model) is employed instead of IMPMC.

K. Shimizu et al., 23th FEC 2010, THD/5-2Ra

Evolution of profiles after the L-H transition

Radial profile in the core

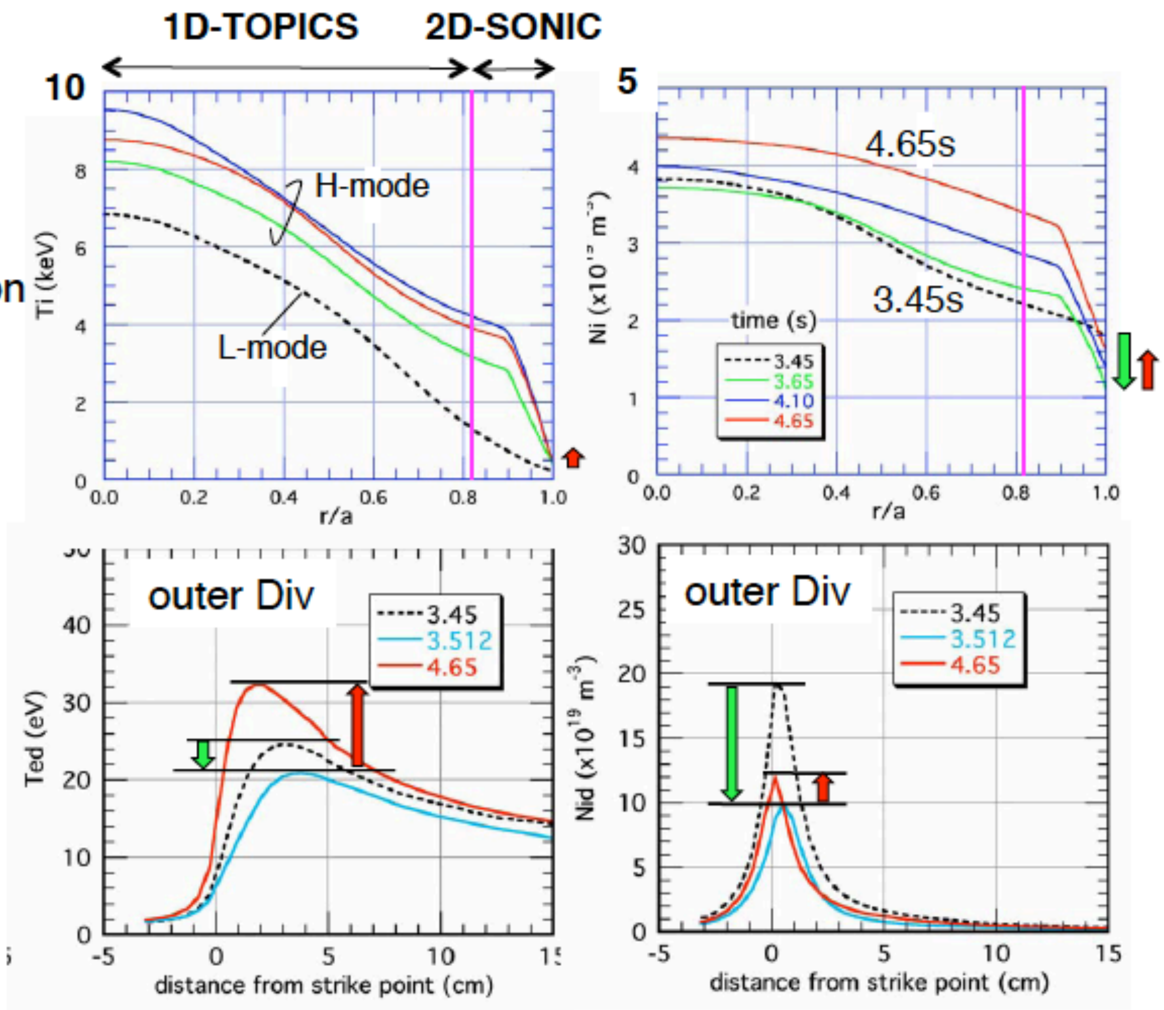
Pedestal Ni and Ti grow up in the H-mode

Separatrix Ni is reduced by reduction in Fi at the transition and gradually increases with the recovery of Fi.

Profile along divertor plate

Peak values of Nid and Ted are reduced by small Fi and Qe after the transition.

Afterwards Nid and Ted gradually increase.



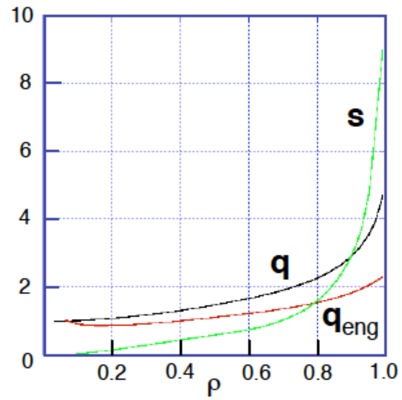
K. Shimizu et al., 23th FEC 2010, THD/5-2Ra

Tuned CDBM Model

$$\chi_{\mathrm{CDBM}} = \frac{c^2}{\omega_{\mathrm{pe}}^2}\frac{v_{\mathrm{A}}}{qR}|\alpha|^{3/2}F(s,\alpha), \qquad \alpha = -q^2R\frac{d\beta}{dr}$$

(K. Itoh et al., PPCF, 1994)

- **At the edge,** $\chi \approx \frac{q^3(1)}{s^{1/2}}$ **can not decrease due to large q(1)**



✓**Modification (I)** **Using Engineering *q***

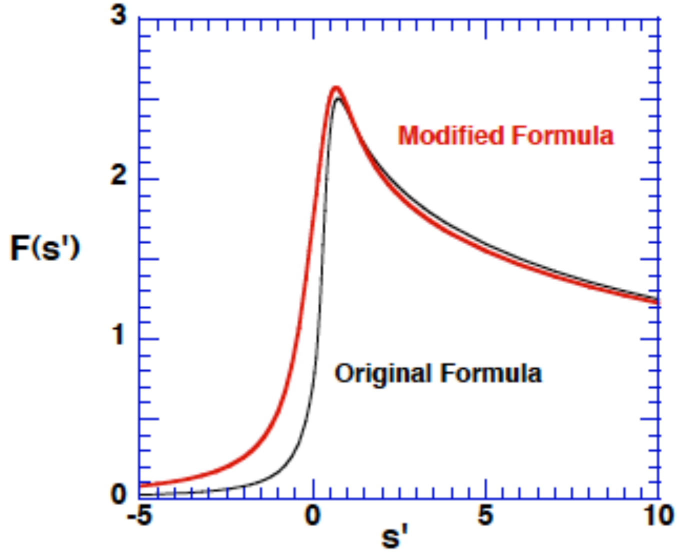
$$q(r) \equiv q_{\mathrm{eng}}(r) = \frac{2\pi\kappa r^2 B_t}{\mu_0 R I(r)}$$

- **In the weak-shear central region, *F* is very small and the ITB can be easily formed by the heating power smaller than an ETB threshold (L-H transition).**

✓**Modification (II)** **Moderate decrease of *F* for $s' < 0$ regime**

$$F(s,\alpha) \equiv F(s') = \begin{cases} \sqrt{3}(1+2s'^{2.5})/(1-s'+1.35s'^2+0.7698s'^3), & s'>0 \\ \sqrt{3}/[(1-s')(1-s'+3s'^2)]^{1/2}, & s'<0 \end{cases} \qquad s' \equiv s-\alpha$$

Tuned CDBM Model (Cont.)



■In the weak-shear central region, ($\omega_{EXB}/\gamma_{CDBM}$) becomes very small and the ITB can be easily formed before the L-H transition.

✓Modification (III) Modification of shear dependence on γ_{CDBM}

$$\gamma_{\mathrm{CDBM}} = |\alpha|^{1/2} \frac{v_{\mathrm{A}}}{qR} F(s') \qquad \text{(J.W. Connor, PPCF 1993)}$$

Tuned CDBM Model (Cont.)

Transport Model $$\chi_{\mathrm{ANO}} = \frac{\mathrm{A}\chi_{\mathrm{CDBM}}}{1+(\mathrm{B}\omega_{\mathrm{EXB}}/\gamma_{\mathrm{CDBM}})^{\mathrm{K}}}$$ **(T. S. Hahm and K.H. Burrell, PoP 1995)**

✓Adjustment of Transport Coefficients

$$\omega_{\mathrm{EXB}} = (RB_\theta/B_t)\,|\mathrm{d}/\mathrm{d}r\,(E_r/RB_\theta)|$$

$$-\,\mathrm{d}p_i/\mathrm{d}r + e\,n_i\,E_r = 0$$

A: $\mathrm{HH} \approx 0.5$ for L-mode

B: L-mode for $\mathrm{P_{loss}} < P_{\mathrm{LH}}$

K: $\omega_{\mathrm{EXB}} \sim |\alpha|,\ \gamma_{\mathrm{CDBM}} \sim |\alpha|^{1/2},\ \chi_{\mathrm{CDBM}} \sim |\alpha|^{3/2}$

$$\chi_{\mathrm{ANO}} \sim \frac{|\alpha|^{3/2}}{1+\mathrm{C}|\alpha|^{\mathrm{K}/2}} \qquad \mathrm{K} \to 3$$ **(Note that K=4 is numerically difficult)**

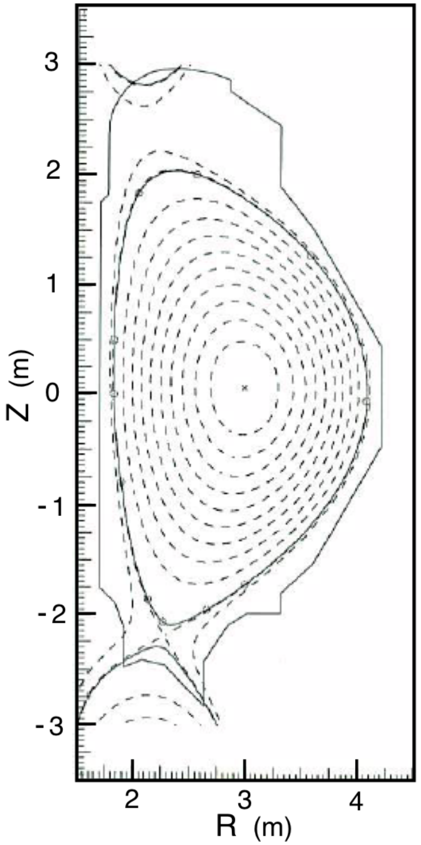
$\mathrm{P_{LH}} = 0.06(B_t n_{20})^{0.7} S^{0.9}$ (MW, T, $10^{20}\mathrm{m}^{-3}$, m^2) **(T. Takizuka, PPCF 2004)**

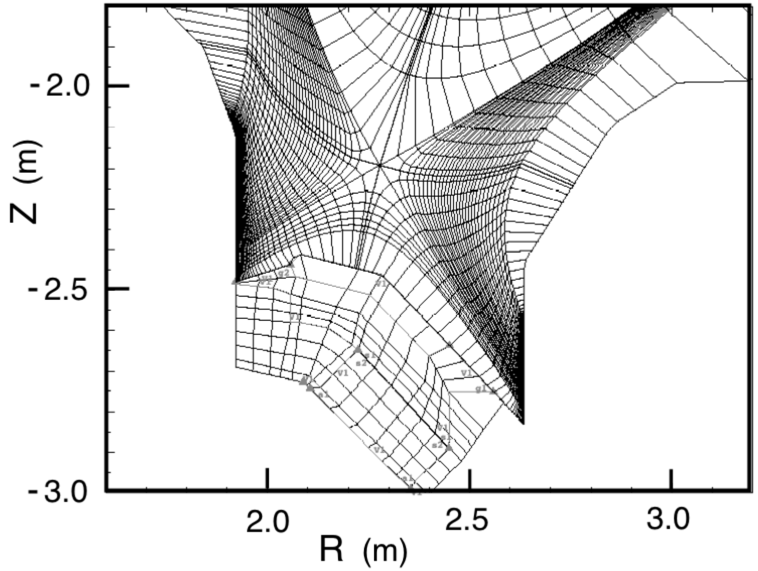
For JT60-SA with

$B_t = 2.3\mathrm{T},\ n_{20} = 0.3\times10^{20}\mathrm{m}^{-3}$ ($n_{\mathrm{GW}} = 1\times10^{20}\mathrm{m}^{-3}$ for $I_p = 4\mathrm{MA},\ a = 1.13\mathrm{m}$), $S = 190\mathrm{m}^2$

$$\mathrm{P_{LH}} \to 5\mathrm{MW}$$

MHD Equilibrium of JT60-SA





MHD equilibrium of a JT-60SA plasma with single-null divertor configuration. R = 3 m, a = 1.1 m, κ = 1.8, δ = 0.55, I_p = 4MA, and B_t = 2.3 T,. 2D mesh configuration for SONIC is also shown.

Scenario of Transport Simulation

(1) Weak heating L-mode Phase

P_{NB} = 0.5 MW is added to a plasma with I_p = 4MA and B_t = 2.3 T.
A slightly-broad current density profile j(r) is given (l_i = 0.7).
Effective charge number Z_{eff} = 2 is set uniformly.
Ohmic heating power P_{OH} is calculated as 3.1 MW.
Radiation power from the core plasma is set P_{rad} = 1 MW.
Line average electron density is $\bar{n}_e \sim 0.25\text{x}10^{20}\text{m}^{-3}$.
The HH factor by the IPB98(y,2) standard is calculated as ~ 0.5.

(2) NB Phase

NB heating is suddenly increased up to P_{NB} = 8 MW at t = 3 s.

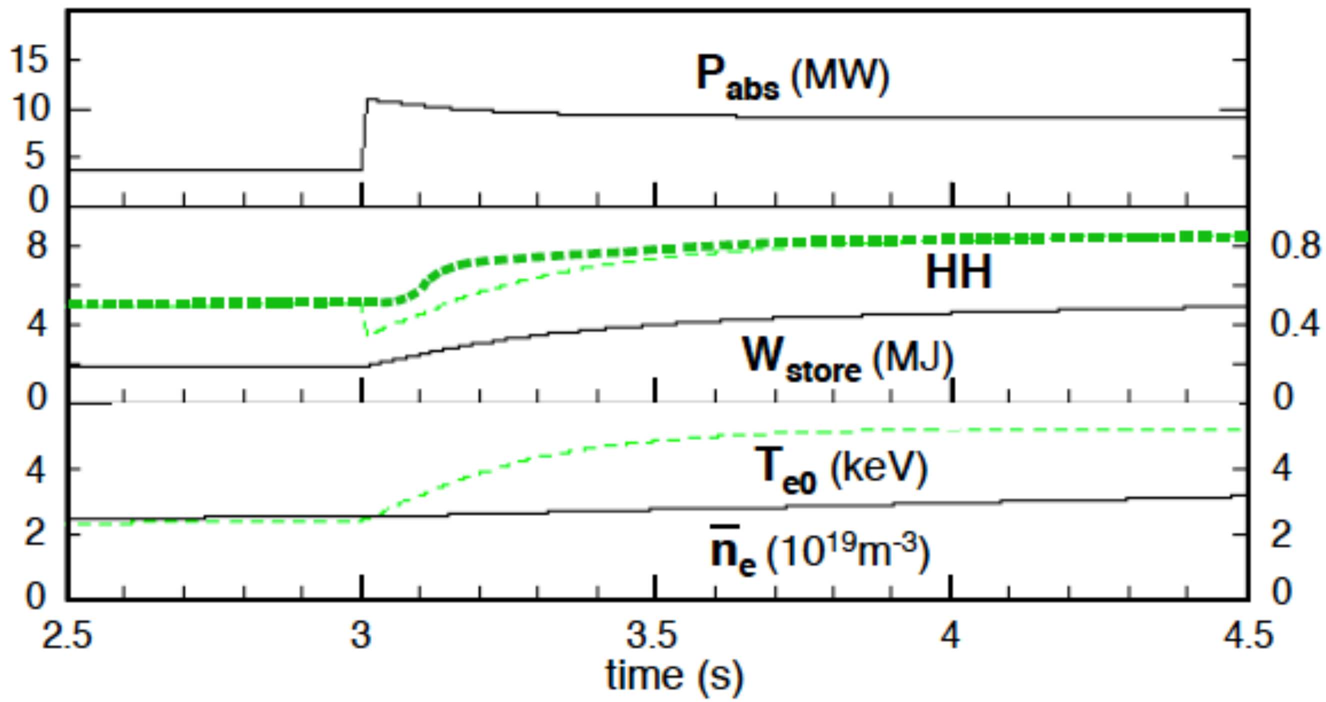
(3) L/H Transition Phase

An L/H transition occurs self-consistently within the present transport model.
Absorbed power at this time, t ≈ 3.1 s, is 10.4 MW including P_{OH} = 2.4 MW. Time variation of the store energy dW/dt = 5.6 MW.

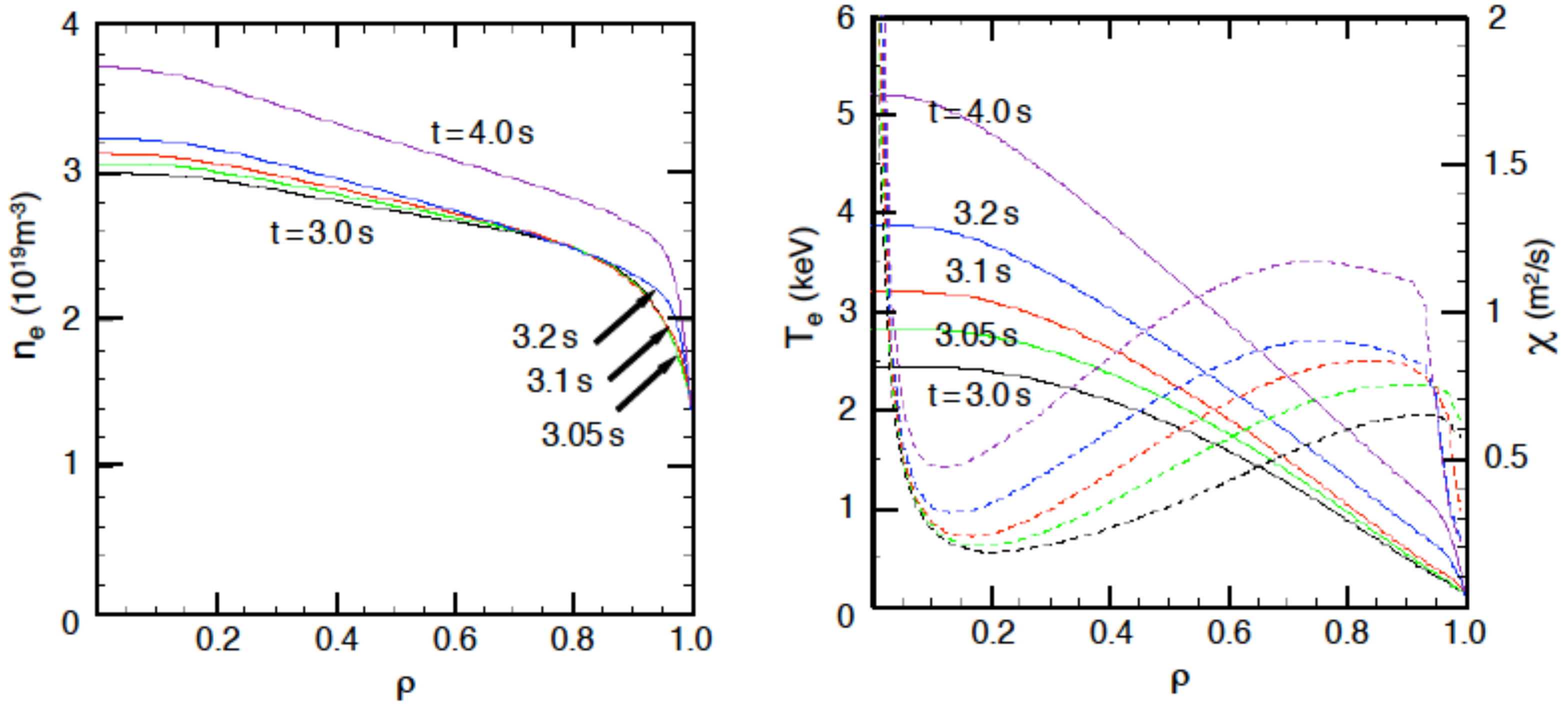
The loss power is estimated as 4.8 MW, which is similar to P_{thr} predicted by the threshold power scaling.

(4) H-mode Phase

The HH factor becomes about 0.85 in the H-mode phase.

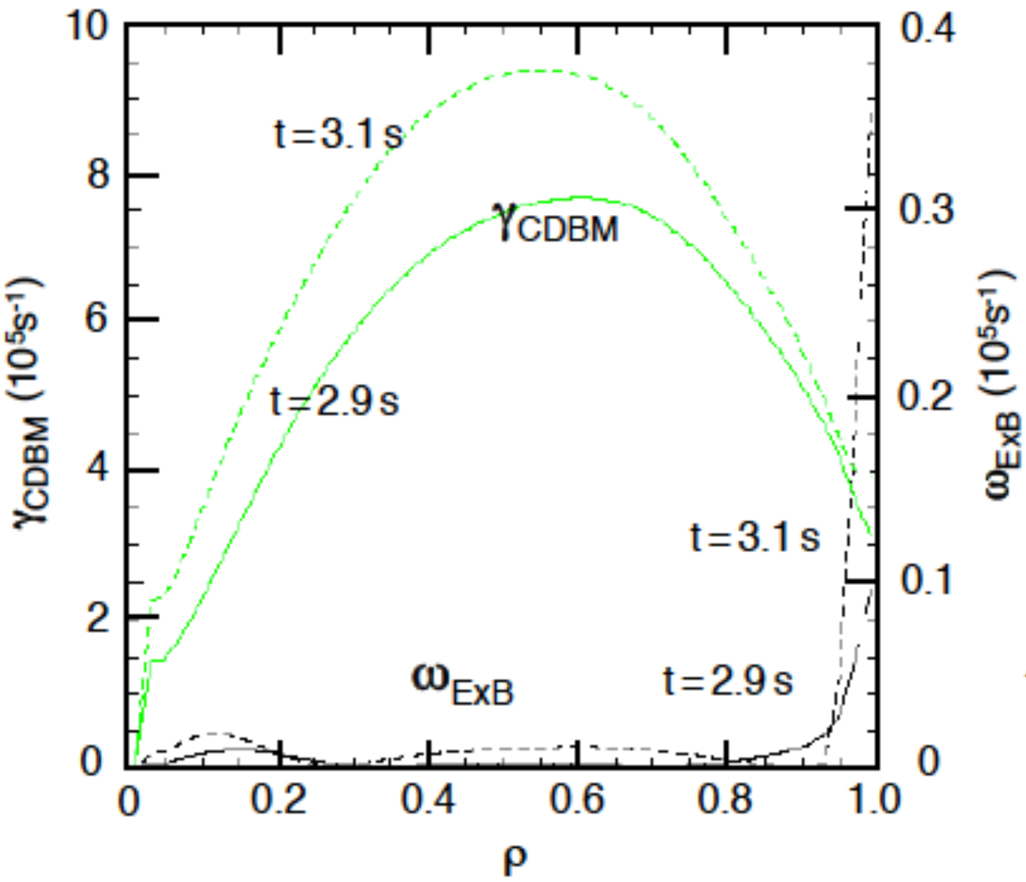


Time Evolution of Density and Temperature in L/H Transition Phase



Evolution of electron density profile $n_e(r)$, electron temperature profile $T_e(r)$, and heat diffusivity profile $\chi(r)$. NB heating power is increased to 8 MW from the time t = 3 s. An L/H transition occurs around t = 3.1 s. χ is drastically dropped in the edge region and the pedestals are clearly formed on n_e and T_e profiles.

Turbulence Suppression by ExB Shearing Rate



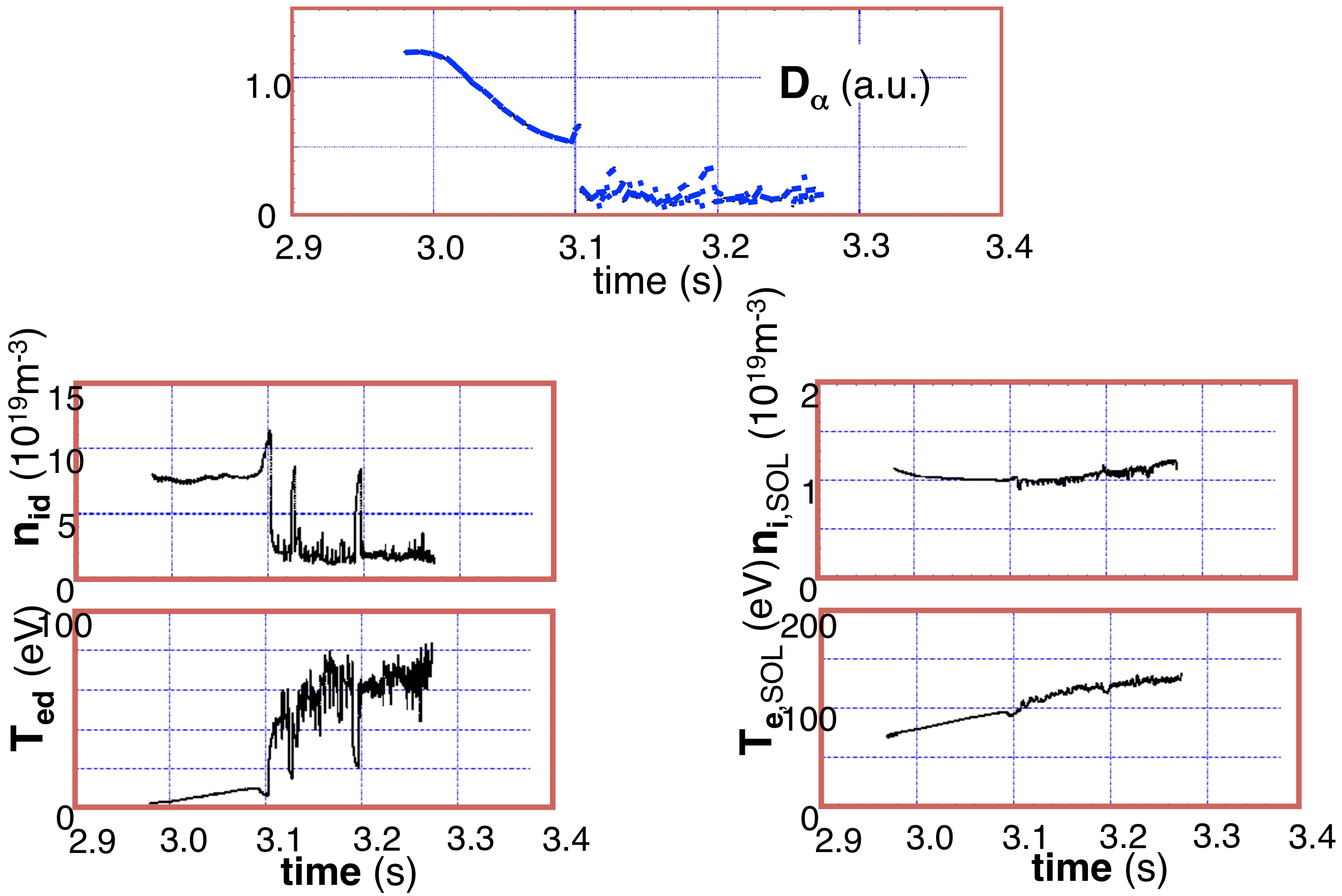
t = 2.9 s : L-mode
t = 3.1 s : H-mode

$$\chi_{ANO} = \frac{A\chi_{CDBM}}{1+(B\omega_{EXB}/\gamma_{CDBM})^K}$$

B = 15, K = 3

After L/H transition, ExB shearing rate increment clearly overcomes the CDBM growth rate increment at the edge region.

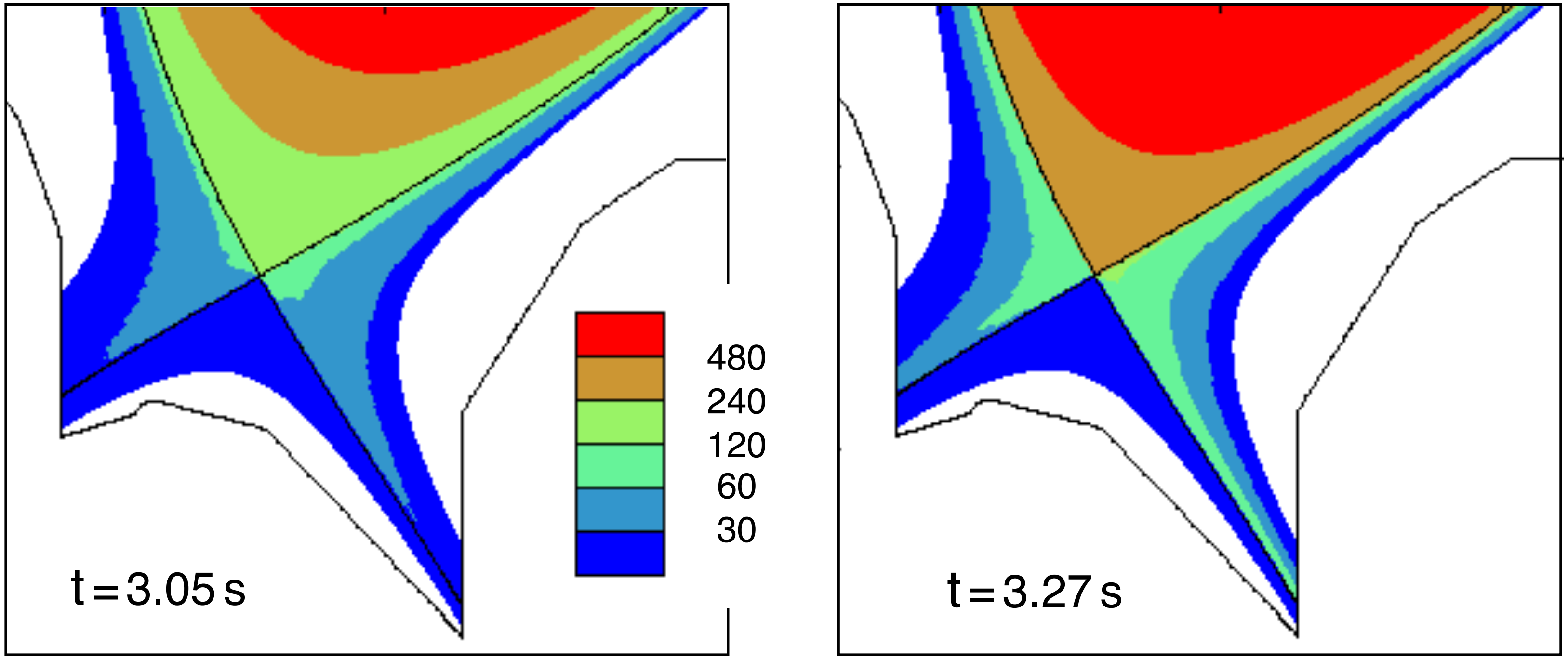
Time evolution of D_α and Profiles by SONIC



Time evolution of ion density and temperature (n_{id}, T_{ed}) at outer divertor strike point and ($n_{i,SOL}$, $T_{e,SOL}$) at outer mid-plane through the L/H transition.

Temporal fluctuation of SOL/divertor-plasma is observed in H-mode phase.

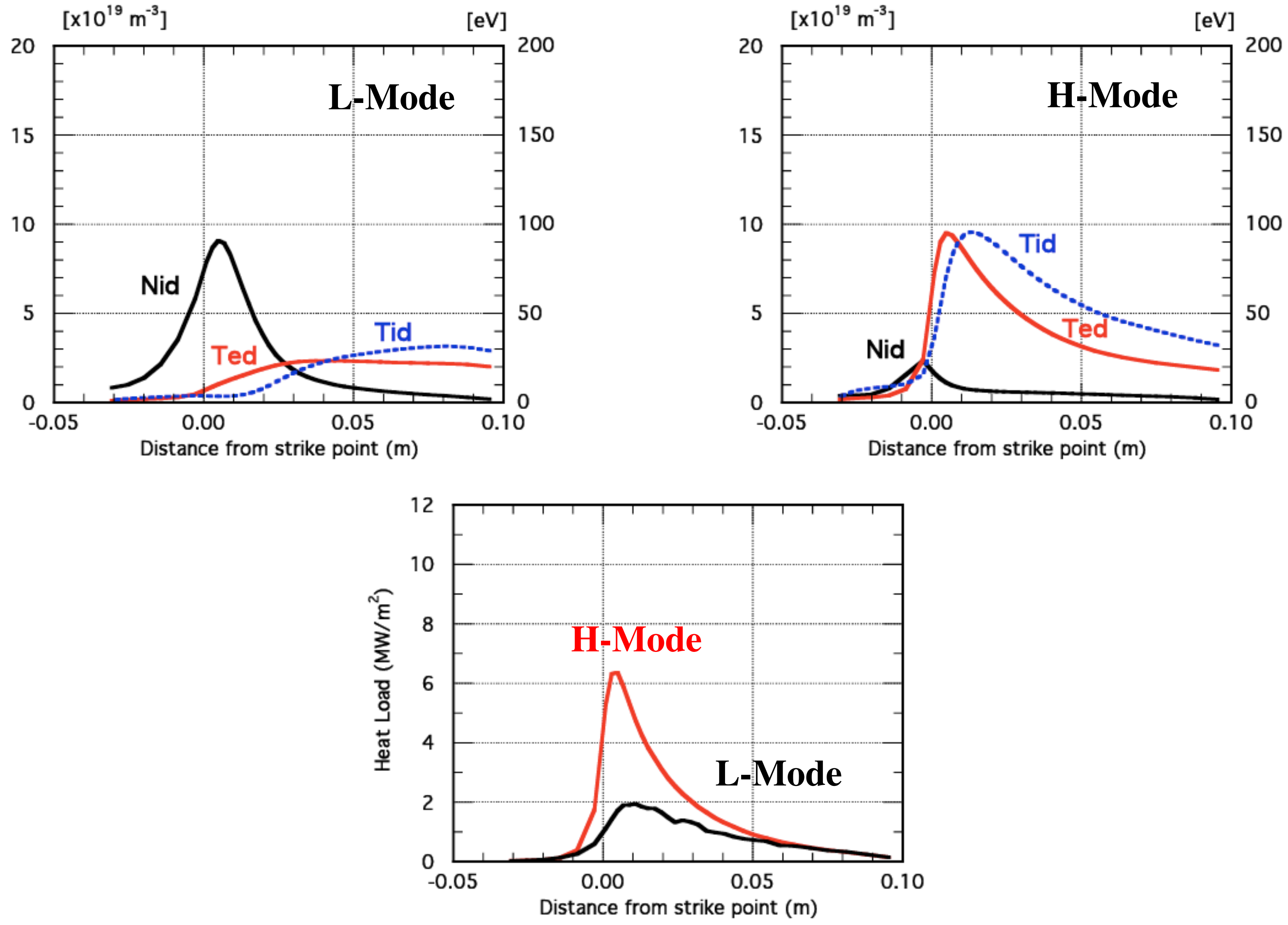
2D electron temperature before and after the L/H transition



After transition, electron temperature increases near divertor plate.

T_{ed} increases from ~10 eV to ~50 eV.

Heat Load on Outer Divertor Plate



Summary

Self-consistent integrated modelling of core and SOL/divertor transport (TOPICS-IB & SONIC) is developed by MPMD parallel computing system.

The dynamic simulation for the L/H transition in JT-60SA is carried out by integrated code with tuned CDBM transport model including the E×B shearing effect.

Impacts of SOL/divertor transport on the L/H transition are studied.
It is found that after the transition, the electron density suddenly drops and the electron temperature increases near the divertor plate.
The temporal fluctuation of the SOL plasma is observed in the H-mode phase.

Examination of the numerical accuracy and analyses on the physical mechanisms are left for future work.